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UK road ice prediction system
Assessing incidence of fog
Journeys to the North Pole
The summer of 1988
Climatological data processing

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A preliminary performance and benefit analysis of the UK national road ice prediction system

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Summary

The ice prediction system is described, and assessments of performance are analysed. The practical benefits in two areas of the United Kingdom are discussed quantitatively, based on winter indices.

1. Introduction

Since the winter of 1986/87 several local authorities in the United Kingdom with responsibilities for road maintenance have made use of computer-generated forecasts of overnight road surface temperatures which may lead to icy conditions. These forecasts are made by the Meteorological Office Weather Centres and disseminated through the 'Open Road' service provided by the Office using software developed by Thermal Mapping International (TMI) which is based at University of Birmingham.

The variation of the temperature of a road surface with time is determined by emitted and absorbed radiation, the turbulent transfer of heat to the overlying air and conduction through the road-bed material (Rayer 1987). Starting from an estimated or measured road surface temperature at 12 GMT the forecast variation of the meteorological elements air temperature, humidity, wind, cloud amount and type, and rainfall, which are involved in the heat budget processes, lead to an estimate of the subsequent variation of surface temperature and a prediction of the occurrence or not of frost and ice. The forecasts can be updated when necessary by monitoring actual measurements of road surface temperatures from sensors at roadside 'outstations' (some of which also provide continuous measurements of the meteorological variables). These forecasts are made for a few widely spaced locations at which there are outstations, but interpolation to a dense network of roads can be made by using the results of thermal mapping surveys. These surveys, made by infra-red detectors in vehicles driven at night, indicate the extent to which different sections of roads cool in different weather conditions.

Local highway authorities use these forecasts to make decisions whether or not to grit or salt roads. Potentially, much directly accountable money can be saved by accurate forecasts of overnight road conditions simply from the cost of materials, labour and administration used in salting or gritting roads. Probably much more non-accountable money can be saved by the reduction in injury, damage and disruption to traffic resulting from reduced numbers of road accidents.

In the following sections of this paper the performance of some aspects of ice prediction systems are described along with indications of the cost savings and benefits to be expected.

2. The scale of operations in the United Kingdom

By the start of the winter of 1988/89 the thermal mapping of more than 21 500 km of roads in 45 highway authority areas had been undertaken in the United Kingdom. More than 320 road weather outstations had been installed in 30 counties or regions and more than 50 counties or regions were taking the Open Road service. Altogether more than £5 million has already been

invested in road weather systems in the United Kingdom compared with the cost of about £100 million for maintenance during an average winter.

These figures bear a very favourable comparison with those for, say, North America (USA and Canada) with 500 km of thermal mapping and 110 outstations, or the main snow- and ice-affected countries of the world (including the United Kingdom) with 34 000 km of mapping and 1700 outstations altogether. For North America snow and ice control is estimated to cost £1200 million per winter, and for the northern hemisphere as a whole the figure is about £2000 million with £20 million (i.e. one per cent of the annual maintenance bill) being spent on road weather systems in the last 5 years.

At present, in the United Kingdom, each highway authority is responsible for its own involvement in ice prediction systems, and there are already signs of regional systems developing such as in Wales (Perry *et al.* 1986). A computer bureau has been installed in Manchester Weather Centre to serve all 14 district and motorway authorities in the counties of Greater Manchester and Merseyside; so far the Boroughs of Stockport, Bolton and Oldham have joined the system. A new bureau is being installed in Leeds Weather Centre potentially to serve the equivalent of 4 counties. The computer bureau at the University of Birmingham is also serving as the central processor for Suffolk, West Midlands motorways, Warwickshire motorways, Staffordshire and Berkshire.

The 14 Meteorological Office Weather Centres around the United Kingdom are ideal hubs for regional systems. It is from these Weather Centres that forecasters provide the crucial human input to the ice prediction models; this consists of forecasts for each 3-hour period of air temperature, humidity, wind, precipitation and cloud. Facilities exist to monitor the performance of the systems and models at the larger Offices at Glasgow, Leeds, Cardiff and London, and at the University of Birmingham Ice Prediction Centre run by TMI.

As the use of ice prediction systems has now become firmly established within highway authorities it is appropriate to review their effectiveness in practice. Forecast thermal maps and ice prediction curves look pretty on the computer screen but how are they used operationally? How long does it take the average highway engineer to learn how to use such information effectively? How can an ice prediction system aid management as well as day-to-day operations? How cost effective is the system? These are the types of question that have been asked, and information is now available to try and answer some of them.

3. The performance of ice prediction systems

The Birmingham Ice Prediction Centre run by TMI is also able to produce statistical summaries which help to assess the benefits to be gained by the system (described in the next section). The following is a sample of results from the monitoring of the system performance.

3.1 Reliability of data supply

A typical county ice prediction system with eight outstations operational from 1 November to 31 March will collect data for about 160 days, or 30 720 hours (8 × 160 × 24). In Cheshire, in the winter of 1987/88 a total of 677 hours of data were lost out of a possible total of 29 184, or 2.3%, due to power and computer failures and defective data lines. It is suggested that the target should be at least 98% data availability.

3.2 Assessment of forecast success

Using input data based on the forecaster's judgement of the expected weather conditions, an ice prediction computer model is run for forecast sites in defined climatic zones within each county/region. The accuracy of these forecasts is assessed which provides feedback to forecasters about how well the road surface temperature and wetness is modelled. For example Fig. 1 shows the accuracy of the forecasts of minimum road surface temperature for the winter 1987/88 for the Ray Hall outstation in the West Midlands. Two forecast variations of road surface temperature are issued, one of which is based on the best estimate of the likely weather conditons (the 'realistic' one) and the other on the worst conditions which could happen, say, rain followed by clearing skies, which is the 'pessimistic' forecast. Fig. 1 shows that the mean error in the minimum road surface temperature for realistic forecasts was −0.3 °C (forecast−true) and −3.4 °C for pessimistic forecasts, for a sample of 113 nights.

An analysis of correct/incorrect forecasts can also be made in terms of the four possible combinations of frost/no frost forecast and frost/no frost occurring. A frost in this context is road surface temperature falling below zero. The potential consequences of the two types of erroneous forecast are different:

Type 1 error: No frost forecast/frost occurs — potential for accidents.

Type 2 error: Frost forecast/no frost occurs — potential for wasting salt etc.

Fig. 2 shows that for the 113 nights the realistic forecast was correct on 87.6% of occasions but this reduces to 66.4% for pessimistic forecasts. For realistic forecasts, both Type 1 and 2 errors occur equally on 6.2% of occasions, but for pessimistic forecasts errors of Type 2 occur on 33.6% of occasions. The percentage of nights on which one or other of the two forecasts was correct is 93.8% with no Type 1 errors.

3.3 Results of surveys of microclimate and thermal mapping

The average minimum air and road temperatures during the winter have been analysed to identify the coldest and warmest sites under differing weather

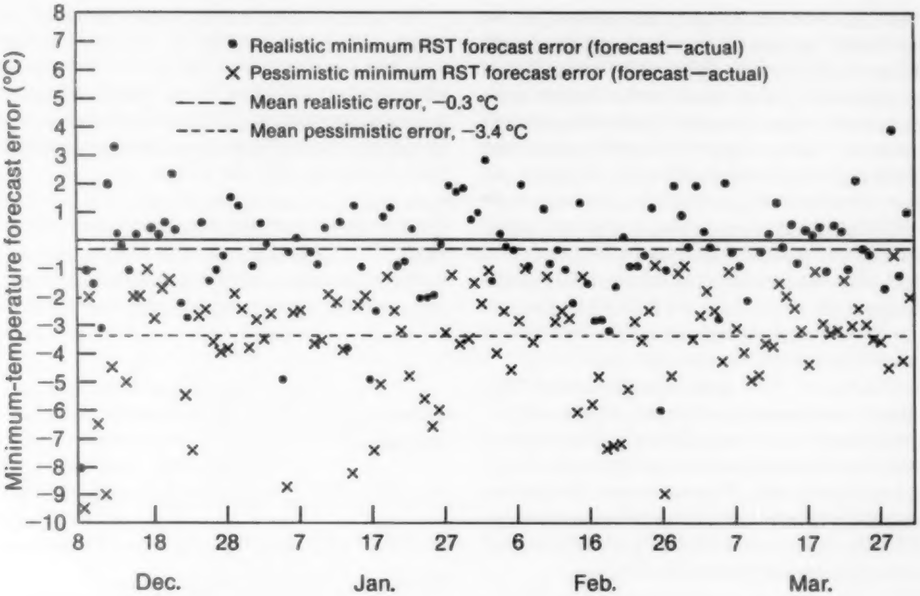

Figure 1. Minimum road surface temperature (RST) forecast accuracy at Ray Hall, West Midlands during the winter of 1987/88 (see text for explanation of terms).

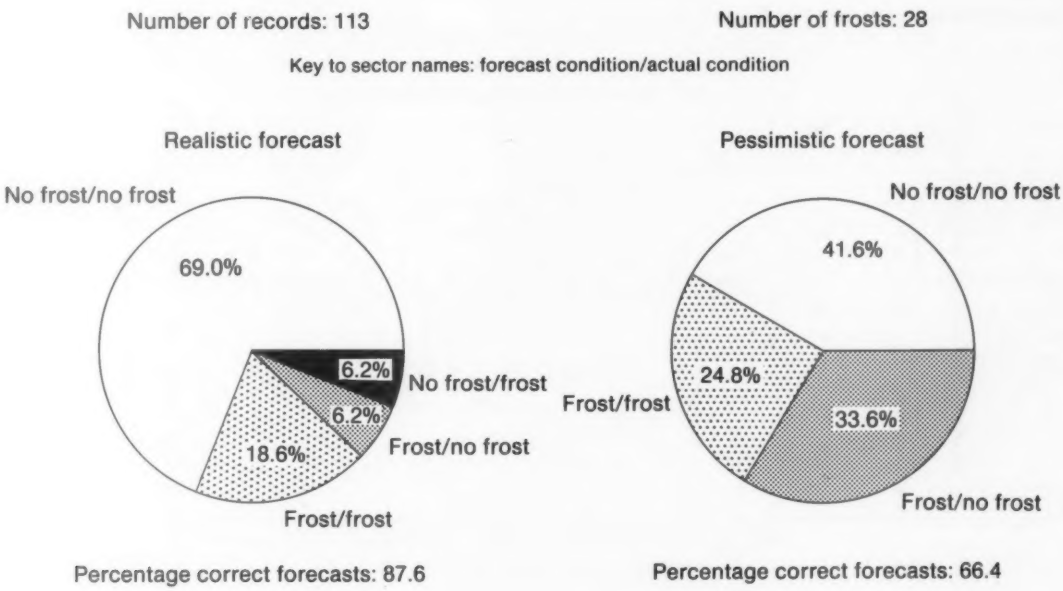

Figure 2. Forecast accuracy displayed in sectors, data as in Fig. 1.

conditions. Fig. 3 shows the average minimum air temperatures at 12 sites in the Hereford and Worcester area at different altitudes for nights with three different weather conditions. These are 'extreme' nights with clear skies and little wind, 'damped' nights with overcast skies, moderate winds and possibly precipitation, and 'intermediate' nights in between. On extreme nights, air temperature increases with elevation by approximately 2 °C in 1500 feet, on average, while on damped nights the temperature decreases with elevation by about 3 °C in 1500 feet. On intermediate nights the temperature again decreases, by about 2 °C in 1500 feet increase in altitude; in the United Kingdom approximately 70% of winter nights fall into the intermediate class.

The significance of these types of night is that they require three corresponding thermal maps of the detailed road network in a region for use in interpolating between the forecast temperature changes for the small number of outstation sites. The forecaster chooses the appropriate map according to the weather conditions indicated by the observations from the outstations and the progression of forecast temperatures.

3.4 Comparisons of model performance

Two models for forecasting road surface temperatures have been used in the 'Open Road' service, which have been developed at Birmingham University (TMI model I, see Thornes 1985, Parmenter and Thornes 1987) and by the Meteorological Office (Rayer 1987). A further model, TMI model II is still under development.

Table I gives results of comparisons of these models where actual measurements of the meteorological variables have been used, rather than forecast variables whose impact of errors would need to be assessed in a separate comparison. The results are based on data for 50 nights (unless otherwise specified) at Coleshill on the M42 during the 1987/88 winter.

Table I. Comparative errors in performance of three ice prediction models (see text for explanation of terms)

Model	TMI I		TMI II		Meteorological Office	
	Mean	r.m.s.	Mean	r.m.s.	Mean	r.m.s.
Comparison						
A	1.15	0.45	0.85	0.33	0.88	0.26
B			0.11	1.49	0.21	1.54
C	1.09	0.79	0.29	0.80	−0.25	0.86
D			−0.54	1.45	−0.16	1.43
E	1.60					

All errors are in the sense (predicted−observed)

A is the r.m.s. error of temperature for 24 values from predictions made at 12 GMT for each hour from 13 GMT to 12 GMT the next day (°C)
B is for maximum road surface temperature (°C)
C is for minimum road surface temperature (°C)
D is the timing of the zero temperature (hours)
E is the same for A but for 114 nights and includes errors of forecasts of meteorological variables.

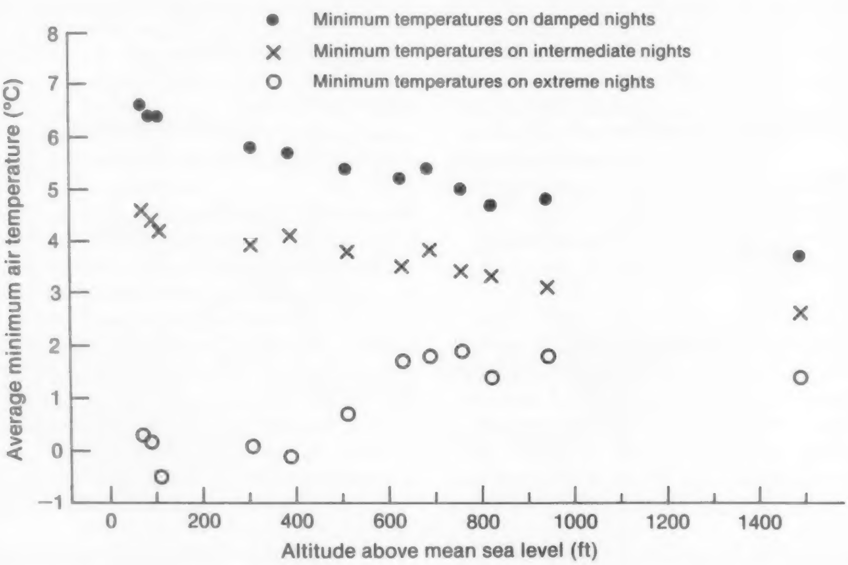

Figure 3. Average minimum air temperatures at 12 sites in the Hereford and Worcester area in winter at different altitudes and weather conditions (see text for explanation of terms).

4. Benefits of the use of ice prediction systems

4.1 Winter indices

In the course of its operations the Birmingham Ice Prediction Service developed two winter indices to study:

(a) The variation of expenditure on winter maintenance from year to year (temporal winter index (TWI)), and

(b) The variation of expenditure across a county or region in a particular winter (spatial winter index (SWI)).

4.1.1 Temporal winter index

This is based on Hulme's index (Hulme 1982) used to assess the severity of a winter (1 November–31 March).

The TWI uses three variables:

(a) Mean maximum air temperature (T, °C) in units of degree Celsius,

(b) Number of days with snow lying at 09 GMT (S), and

(c) Number of nights with a ground frost (F)

such that

$$TWI = (10 \times T) - (18.5 \times S)^{\frac{1}{n}} - F$$

where n = 3 in the United Kingdom (but less in areas with more snow).

For example, in Fig. 4 is shown the yearly variation of TWI at Manchester (Ringway) relative to the mean for 30 years so that cold winters now have a negative index (anomaly) and warm winters a positive index.

The lowest and highest TWIs for Manchester are −55 (winter 1962/63) and +38 (winter 1973/74) but the winter of 1987/88 was the first to have a positive TWI since 1982/83. For planning purposes based on the 30-year sample it can be seen that most winters in this area will have a TWI in the range −25 to +25 (20 out of 30) but for 1 in 3 winters the index will be outside this range. There have been 5 winters with a TWI of −25 or less, so there is a 1 in 6 chance of a winter being this cold.

These figures for Manchester are typical of the area covered by the highway authorities served by Manchester Weather Centre. TWI values have been calculated for the locality of each weather centre.

4.1.2 Spatial winter index

Not only do winters vary from year to year but the severity of road conditions will vary across a region due to the geography of an area and the road construction and traffic. For instance Cheshire County has relatively warm motorways like the M6 running north/south at a modest elevation but also lesser roads climbing up into the Pennines. As an example consider the night minimum temperatures during the winter 1987/88 for the Cat and Fiddle outstation at 1686 feet (514 m) compared with those for Hassall Green on the M6, at 259 feet (79 m). The two sites are only 50 km apart but the Cat and Fiddle had 65 nights on which the road temperature fell below 0 °C whereas Hassall Green had only 28 nights.

An SWI can be defined in terms of a count of the relative number of wet and dry frosts. A dry frost occurs when the road surface temperature falls below 0 °C but the road remains dry. A wet frost occurs under the same

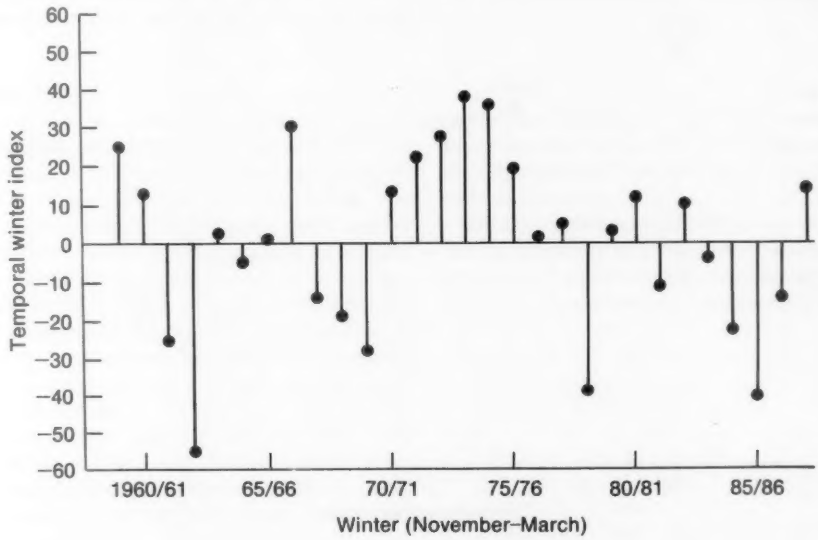

Figure 4. Values of temporal winter index (TWI) at Manchester (Ringway) for the winters shown, commencing in November. See text for explanation of TWI.

conditions of temperature but there is moisture present on the road which may be rain, snow, hoar frost or be caused by the hygroscopic nature of salt on the road. The Cat and Fiddle and Hassall Green outstations represent the extremes among the 8 sensors in the Cheshire County area — the Cat and Fiddle had 6 dry and 59 wet frosts and Hassall Green 15 dry and 11 wet frosts.

This SWI can be related directly to the maximum number of salting runs that should have been necessary in the vicinity of an outstation sensor site. In snow conditions or with showers about, multiple salting runs may have been necessary but the index gives a good guide to possible nights with under- or over-salting.

Also it is necessary to know how representative of the road network the sensor sites are, over a region, and this requires extensive thermal mapping. Again taking Cheshire with its 8 outstations as an example, this area has three operational divisions — East, West and Motorways — and it is possible to devise an average SWI for each division.

4.2 Analysis of salt usage in two areas

4.2.1 Cheshire

The TWI for six winters has been compared with salt usage figures supplied by Cheshire County Council. The index is calculated for Manchester and has to be assumed to be representative of the whole of Cheshire; also the usages are for the whole county and probably no more accurate than ±1000 tonnes. In Fig. 5 the winter usages are plotted against the TWI showing the expected inverse relationship. Cheshire County Council installed their ice prediction system at the start of the 1986/87 winter but there was no obvious reduction in salt usage in that winter (possibly the start of a learning process?). From a linear regression applied to the five points for the winters 1982/83 to 1986/87 in Fig. 5, the predicted usage for the winter 1987/88 is 16 100 tonnes compared with the actual usage of 13 050 tonnes; this 20% reduction is attributable to the use of the ice prediction service. Further monitoring of salt usage in Cheshire for another 3 years is planned, so that firm conclusions can be drawn about savings.

4.2.2 Hereford and Worcester

Ponting (1984) has produced a detailed examination of salt usage by Hereford and Worcester County Council. He showed that during the winter of 1983/84, forecasts of wet frosts were successful on only 57% of occasions resulting in a wastage of approximately 30% in salt usage. During 1987 the Council installed an ice prediction system and an identical study was carried out on salt usage during the winter 1987/88, as for the earlier winter (not dissimilar in weather), representing a useful 'before and after ice prediction' comparison. Preliminary analysis shows that the success rate of accurate wet frost forecasts increased to 91% and salt wastage reduced to 15%. Over the last 10 years this Council has used an average of 18 620 tonnes of salt each winter; the cost of salt is about £20 per tonne so that the reduction of wastage to 15% represents an average winter saving of £56 000 just for salt. Reduced labour costs, wear and

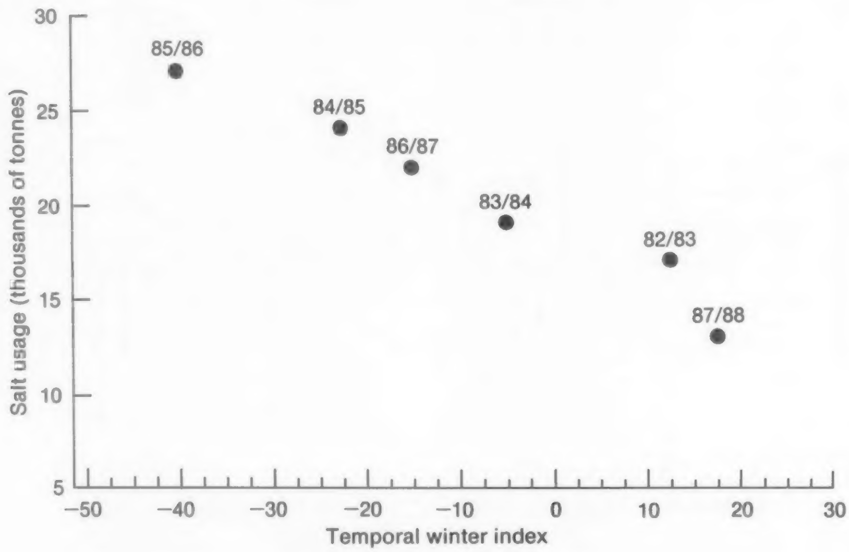

Figure 5. Cheshire County Council's salt usage for the winters shown plotted against the temporal winter index (TWI) at Manchester (Ringway) for the specified winters.

tear on equipment, etc. increases the annual saving considerably over this figure.

Using the TWI for Birmingham (the nearest available location) the salt usage for 1987/88 was predicted to be 12 333 tonnes based on linear regression of figures for the previous 9 winters, compared with the actual usage of 7950 tonnes. This is a 35.5% reduction in salt usage (equivalent to £88 000) attributable to the beneficial guidance from the ice prediction system in its first winter alone.

5. Conclusion

By careful monitoring of the performance of an ice prediction system it is possible to show that significant real savings have been made by highway authorities that have installed them, but more data are required to confirm and refine the assessment of the benefits. Particularly, the assessment of improved road safety leading to reduction in accidents is required, as well as accountable savings in the cost of road winter maintenance operations. It is hoped that future statistics will show that there are less accidents caused by ice, frost and snow as the increased use of ice prediction systems enable highway authorities to decide more successfully when to salt roads.

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Current techniques for assessing (indirectly) the localized incidence of fog on roads*

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Summary

This paper describes the methods currently employed by the Meteorological Office when required to determine the likely incidence of fog on planned or existing roads.

1. Introduction

The effect of fog on roads is well known. It impedes traffic and contributes to accidents, especially on high-speed roads and is reported to be that aspect of the weather that drivers fear most (Musk 1982). The number of occasions with fog in the United Kingdom has decreased over the last 25–30 years (Fig. 1) thought to be due mainly to the introduction of 'clean air' legislation in the late 1950s; although meteorologists had noted a decline in the number of dense fogs in London well before that time (Thornes 1978). However, interest in the subject of fog on roads has increased judging by the number of enquiries received by the Meteorological Office over the last few years. The enquiries usually require the identification of areas where fog is most likely to develop or persist (fog-prone areas) on existing, or planned, main roads and motorways. Occasionally the Office is asked to comment upon two alternative routes for a proposed scheme, e.g. the Department of Transport's preferred route and that of local objectors.

Studies carried out in the Office have concentrated on the identification of areas prone to radiation fog, the formation of which is highly dependent upon topography; hence favoured areas for radiation fog formation are

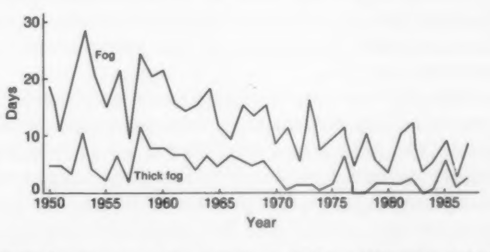

Figure 1. Number of days with fog (visibility < 1000 m) and thick fog (visibility < 200 m) at 0900 GMT at Manchester Airport 1950–87.

*This article is based on a paper presented at the Fourth International Road Weather Conference on 'Meteorology and Road Safety' in Florence, Italy, 8–10 November 1988.

identified relatively easily. Radiation fog is potentially the most dangerous to drivers, as it can be dense and also patchy, and hence the cause of sudden changes in visibility. When appropriate, areas prone to hill fog (caused by low cloud) have also been considered, e.g. areas over 150–200 m above mean sea level. Advection fog is not considered in this paper as it can occur over large areas, regardless of topography and no favoured locations can be identified.

As well as identifying fog-prone areas, an estimate of the number of occasions when fog is likely to occur is also usually required, with emphasis on the lower visibility thresholds (say < 200 m) which would be of most relevance to drivers. In attempting to answer these enquiries, various techniques have been employed and developed by the Meteorological Office. These are:

(a) topographical studies, using maps and route tours,

(b) analysis of visibility and cloud-base data held in computer archives by the Meteorological Office,

(c) obtaining local knowledge from traffic police, local authorities, motoring organizations and weather observers,

(d) aerial thermal mapping by aircraft and satellite, and

(e) deriving the localized fog climatology using a 'fog potential index'.

2. Identification of fog-prone areas

2.1. Topographical studies

When trying to identify areas where fog is most likely to occur, the first step is to study relevant maps or plans. Usually 1:50 000-scale maps or 1:10 000-scale plans together with longitudinal cross-sections, if available, are used. Features such as river valleys, high ground and land use can be identified from the maps, and slope angles can be calculated to estimate potential katabatic drainage into an area. More detailed information about a route can be obtained from the longitudinal cross-sections, which reveal any dips or hollows in the profile, as well as, for example, the size of embankments and cuttings. These cross-sections are especially useful when considering planned routes.

Currently the information concerning land use and topography (e.g. slope angles) is analysed by hand. However, in the future, digitized UK topographic and land-use data sets at 200 m resolution for the United Kingdom could be used to calculate these parameters automatically.

After the map study has taken place, usually at least one route tour of the area is undertaken in order to assess those places already identified as being potentially fog prone and check for any other areas not so apparent from studying maps. The purpose of the tour is not to look for fog, but simply to identify possible fog-prone areas, therefore all tours take place during daylight hours, in fine weather. For a proposed route, an area is generally visited with a local engineer or planner who knows the route and its layout. Such a route is generally viewed from existing roads, before any construction work has begun. Photographs are usually taken of those places thought to be of relevance.

2.2. Use of visibility and cloud-base data

2.2.1 Visibility data

The Meteorological Office's climatological database contains hourly visibility observations from about 70 synoptic stations for at least the last 17 years (many of them have records of over 30 years). Also, daily visibility data (as observed at 0900 GMT) are archived for hundreds of climatological stations for about the last 25–30 years. The data can be analysed in many ways using flexible computer programs to produce averages or frequency analyses.

Visibility information from the nearest Meteorological Office observing station may provide useful initial guidance about fog in the area. However, it is unlikely that conditions experienced at the station will reflect exactly those at a different site because of changes in topography that could occur over a short distance. The visibilities data can, however, be used to reveal trends in fog formation from hour-to-hour, month-to-month and year-to-year, as well as the relationships between the frequencies of occasions with visibility below various thresholds.

As a typical example Fig. 2 shows the variation of the average number of occasions per year at Gatwick Airport with visibility below 200 m as a function of

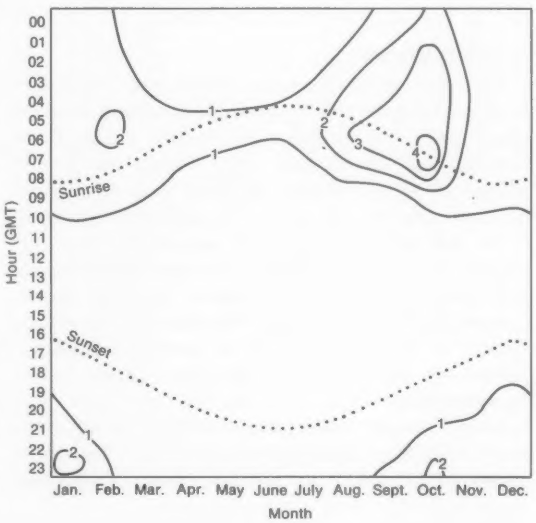

Figure 2. Average number of occasions with thick fog (visibility < 200 m) at Gatwick Airport.

month and time of day. Various features can be identified:

(a) the maximum occurrence of 'foggy occasions' during the early hours of the morning, i.e. the time of maximum cooling on 'radiation' nights,

(b) an absence of foggy occasions during daylight hours irrespective of season, and

(c) the persistence of foggy occasions through more hours of the day during the late autumn and winter months (because of the reduction in insolation).

Analysis of data from many synoptic stations suggests that these features, which are consistent with radiation fog formation, are broadly representative of many low-lying inland sites. Such features can also be identified when lower visibility thresholds are considered.

In general, the times with the greatest occurrence of fog are before the morning 'rush hour', although in the late autumn and winter months there is a risk that the peak traffic flow will coincide with foggy conditions.

2.2.2 Cloud-base data

For those places where hill fog is likely to occur, analysis of visibility data may not be appropriate. This is because almost all of the hourly UK synoptic stations are at relatively low-lying sites and any low visibilities recorded will be due to radiation or advection fog and not to hill fog. However, an analysis of low cloud-base data will give an indication of the number of occasions when hill fog is likely to occur.

For example, if there were a total cover of stratus with its base at a height of 150 m above Gatwick Airport (which itself is 60 m above mean sea level), then visibility might be reduced on nearby high ground with an altitude of greater than 210 m, for instance the North Downs.

The seasonal and diurnal trends in the occurrence of stratus (at inland locations) are similar to those of radiation fog (described earlier). There is a maximum occurrence during the winter months and fewer occasions during the daylight hours of the remaining months (due to the effect of insolation).

2.3. Obtaining local knowledge

When considering an existing road, it is usually possible to identify people who know something about the incidence of fog in the area, such as where patchy/localized fog tends to form first or occurs often, and where fog-related accidents have occurred. Such people include the police and representatives of local authorities and the major motoring organizations, and their local knowledge is very valuable. This information can provide a useful check against locations identified by other means. However, a route tour, after this local knowledge has been gathered, may be necessary to confirm (or otherwise) the locations as being fog prone.

For a study of the M25 London Orbital Motorway, arrangements were made with the motorway police to take note of the locations where fog occurred during a 5-month winter–spring period. Estimates of visibility and brief descriptions of conditions, e.g. patchy fog, drifting fog, blanket fog, etc. were also provided. Obviously, occasions with localized, patchy fog were of most interest.

For a proposed road scheme the police, local authority, etc. may not have any local knowledge about fog in the area, unless the proposed route happens to follow an existing road closely. However, the observers at the weather stations administered by the Meteorological Office, as well as 'amateur' weather observers are often sources of quite detailed and useful information about the incidence of fog in a particular area.

2.4 Identification of fog-prone areas using remote sensing

Two methods have been used to identify fog-prone areas using remote sensing:

(a) directly detecting the presence of fog using Advanced Very High Resolution Radiometer (AVHRR) data from polar-orbiting satellites, on suitable radiation nights, and

(b) detecting fog-prone areas, using an infra-red camera mounted on an aircraft flown on radiation nights, to identify areas which are cooling down quickly and/or those places where cold air may be collecting, i.e. potentially the places where radiation fog may form first.

2.4.1 Satellite data

The identification of fog during the daytime is relatively simple using visible satellite information. However, as radiation fog is the main interest, night-time occasions need to be studied. This causes problems as there are no visible data at night and with infra-red data it is difficult to distinguish the fog from the surrounding area. However, techniques have been developed to detect fog at night based upon the fact that fog and low cloud have different emissivities at different wavelengths, and the use of AVHRR data. AVHRR data are available in five spectral bands, three of which are situated in 'atmospheric windows' in the infra-red region, at 3.7, 11 and 12 μm. At the 11 μm wavelength, fog and stratus have an emissivity of approximately 1.0 and so the brightness temperature (inferred from the radiance) almost equals the temperature of the fog/cloud top. At the 3.7 μm wavelength, the emissivity is approximately 0.8–0.9, and the brightness temperature is significantly lower than the physical temperature. This property is not exhibited by land or sea surface to the same degree, and so this difference in temperature can be used to identify fog on suitable nights (see Eyre *et al.* 1984 for a more detailed explanation). However, the resolution of the satellite data is relatively coarse; each measurement of brightness temperature is an average for an area of 1–2 km^2. Consequently small areas of fog cannot be identified, yet it is on the more local scale that information is required. Also, using this

technique, it is difficult to distinguish between stratus and fog, although the satellite information can be chosen to coincide with known foggy nights to eliminate this problem.

2.4.2 Aerial thermal survey

The information obtained from an aircraft-mounted infra-red camera is far more detailed than the satellite data with a resolution of about a metre, so, for example, individual trees and cars can be identified. At a flying height of about 1500 m each frame of information covers approximately 2 km × 2 km, so detailed information about the radiation being emitted by the road surface, and more importantly by the surrounding area, is obtainable. By calibrating the infra-red image with temperature data, collected by instruments on the ground during the flight the image can be converted into a thermal picture. For ease of interpretation, ranges of surface temperature are represented by different colours (Beaumont *et al.* 1987). The spatial variability in emissivity is not taken into account, causing some errors in the estimated surface temperatures. During a survey where 'observed' surface temperatures ranged from −4 to +8 °C, these errors are calculated, using the Stefan–Boltzmann equation (and more appropriate emissivities for different surfaces), to be generally within 2 °C for the typical surfaces of water, bare soil and trees. For a fog study, however, absolute surface temperatures are not as important as the differences between surface temperatures. On radiation nights this thermal contrast between surfaces will be great, especially around dawn, when maximum cooling is likely to take place. On such nights, the areas which appear the coldest are valley bottoms, areas of bare soil or marshy areas and large road cuttings. The warmest are built-up areas and the deeper bodies of water such as lakes and rivers. High ground also appears warmer on radiation nights, as the cold air has drained off the higher ground and collected in low-lying areas. These variations are all as would be expected from physical considerations. For example, the relative warmth of the surface of a deep body of water at night-time is a result of high specific heat and absorption of daytime radiation to a considerable depth, and also good conduction and convective processes transferring heat to the surface at night.

Aerial thermal surveys provide very detailed information about those places which are cooling down quicker or where cold air is collecting. By combining the survey information with the other data described, including proximity of roads to moisture sources, it is possible to identify the places where radiation fog is most likely to develop. An example of an aerial false-colour image of surface temperature is shown in Fig. 3 with areas of different surfaces — roads, houses, grass, woods and water — indicated. This image and the accompanying map show a section of the M25 motorway near Byfleet in Surrey.

3. Estimating the number of days with fog

Having identified areas where fog is likely to develop, an estimate of the number of occasions when fog is likely to occur is required. For places prone to hill fog, cloud-base data may be used (as described earlier). For places

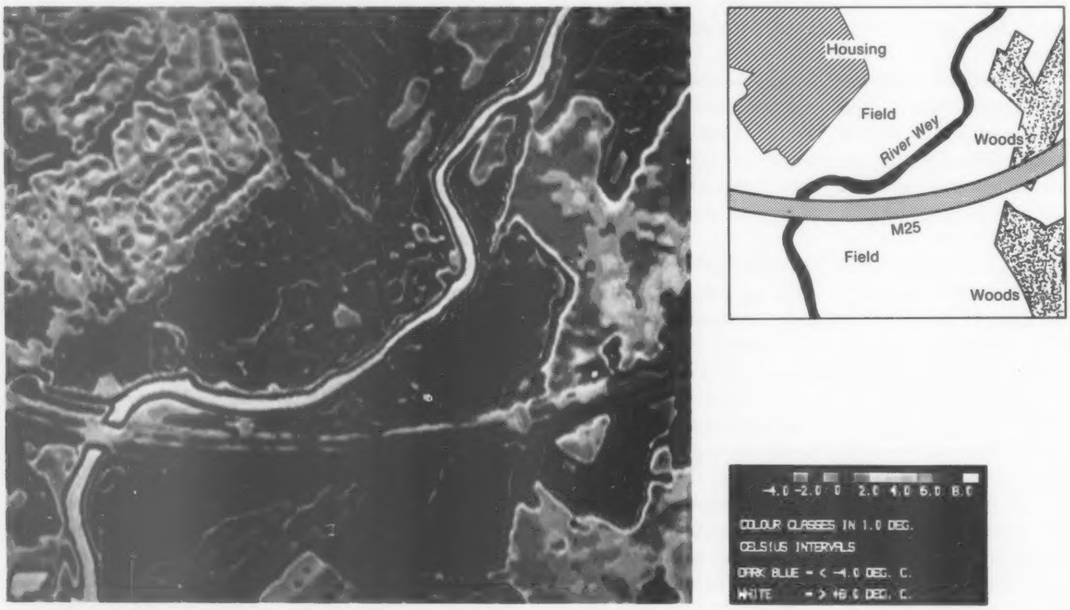

Figure 3. An example of an aerial false-colour image of surface temperature together with a location map of the area.

where radiation fog is likely to be a problem, various techniques have been developed.

A method was proposed by Musk to assess the potential of any site for experiencing radiation fog, known as the 'fog potential index' (Musk 1978). The index attempted to assess a site in terms of those criteria thought most relevant to radiation fog formation, i.e. topography, proximity to water sources, road layout and environmental features. Each criterion was then weighted according to its importance to radiation fog formation to produce the following equation:

$$\text{Index} = 10dw + 10tp + 2sp + 3ep$$

where dw relates to water sources (value increases with proximity to water and extent of water body), tp relates to local topography (value increases with a site's potential for trapping cold air draining off slopes at night), sp relates to site topography (value increases if the road is in a cutting which could trap cold air, or if the road is sheltered), and ep relates to environmental features (value increases with proximity to a rural location or pollution source).

To obtain the index for a site, large-scale maps and plans were used to allocate values between 0 and 4 (in increments of ½) to each factor dw, tp, sp and ep. The maximum value of the index was 100 ($10 \times 4 + 10 \times 4 + 2 \times 4 + 3 \times 4$) representative of, say, a sheltered, rural, river valley. Musk's model did not attempt to estimate the number of occasions with fog, but it provides a very useful method for comparing the potential 'fogginess' of different sites.

Attempts were made to take this technique one stage further and estimate the annual average number of days with fog for different sites. This was achieved by correlating occasions with low visibility at several Meteorological Office stations, with fog-potential indices calculated for each station, using amended forms of Musk's equation (incorporating different weightings and a simplified topography factor). Two approaches were adopted:

(a) indices were calculated for 33 Meteorological Office stations for which annual averages of the number of days with visibility < 1000 m and < 200 m at 0900 GMT had been calculated for the period 1971–86, and

(b) indices were calculated for 14 hourly synoptic stations for which annual averages of the number of days with visibility < 1000 m, 300 m, 200 m and 100 m at 0600 and 0900 GMT had been calculated for the period 1971–86.

The stations chosen were all inland, generally low-lying sites, likely to experience some radiation fog, with the average number of fog days ranging from 10 to 40. Some of these fog days will be due to advection fog, but these make up only a small proportion of the total. The averaging period, 1971–86, was chosen to represent the visibility conditions experienced today as the introduction of the 1956 Clean Air Act has played a major role in reducing the number of occasions with fog since the late 1950s in the United Kingdom.

The best correlation occurred when the lower visibility threshold of 100 m and the hour of 0600 GMT (rather than 0900 GMT) were considered. The correlation enables an index calculated for any site to be readily converted into an estimate of occasions with visibility < 100 m at 0600 GMT.

Further analyses of visibility data from Meteorological Office stations have produced factors relating the number of occasions with visibility < 100 m at 0600 GMT to the number of occasions with visibility < 100 m at 0900 GMT and also to the number of occasions with visibility < 1000 m, 300 m and 200 m at 0600 and 0900 GMT. Hence a fog-potential index can be converted into the number of occasions when visibility falls below these four thresholds at either of the times considered.

The calculation of the fog-potential index is subjective and, when a large number of points has to be considered, time-consuming. Currently, however, the feasibility of using the high-resolution topography and land-use data set (described in section 2.1) to carry out objective calculations is being tested. Computer-plotted colour-coded maps of fog-potential indices in an area with a resolution of 200 m × 200 m have been produced. However, their production is still very much in the experimental stage but it is envisaged that the automatic production of fog-potential indices will play a major role in future fog-study work.

4. Conclusions

The various methods described are available for locating areas prone to radiation fog and for estimating the number of days with fog at each location. For estimating the number of days with hill fog, low cloud-base information can be used as a data source.

The methods have been used to answer many enquiries about fog on roads. Although the format and content of each fog study is generally similar, the use to which this information will be put varies with the stage that a particular road scheme has reached. If a scheme is at the planning stage and several proposed routes exist, e.g. the A34 Newbury Bypass and the A30 Exeter–Honiton Relief Road, then the study can be used to help choose the least foggy route or to avoid potentially foggy areas. If a scheme is at a planning stage but the final route had been decided upon before a fog study was produced, e.g. the M20 (Maidstone–Ashford) and the Birmingham Northern Relief Road, the study will highlight those areas where fog may be a problem and possible changes in road layout (such as using a bridge to cross a valley) or a review of lighting requirements may take place.

For existing roads, e.g. the M42 and M54 motorways in the West Midlands, a fog study can only be used to

review lighting facilities in fog-prone areas or suggest areas where extra warning signals may be necessary.

The most recent fog study to be completed was for the 180 km of the M25 London Orbital Motorway. Various locations were identified as being potentially fog prone (mainly radiation fog, but occasionally hill fog). At most of these locations, fog-detecting equipment will be installed in late 1989, which will be linked to warning signals on the motorway. Hence, when a detector records visibility below a predetermined threshold, for a certain length of time, the signals will be activated to warn drivers of potential danger ahead. It is intended that the visibility data will be archived and made available to the Advisory Services Branch of the Meteorological Office. The data can then be analysed to test the accuracy of the estimates of the number of days with fog at each location and hence provide useful feedback about the techniques currently being employed.

Acknowledgement

The author would like to express her thanks to colleagues within the Advisory Services Branch, especially M.J. Prior, for their helpful comments during the preparation of this paper.

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Journeys to the North Pole and back

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Summary

This article describes the preparations for and phenomena observed during two Polar flights.

1. Introduction

In December 1987, the Meteorological Office at Kinloss in Scotland was asked by the Royal Air Force to provide details of the expected low-level flying conditions at the North Pole during late April and early May with a view to carrying out an operational task the following year. This is a documentary account of the work done by the Meteorological Office in preparing for the trips which have since been given wide publicity in the national media, along with a brief account of the meteorological aspects of the actual journeys which I was fortunate to undertake.

2. Preparation

In the first instance, contact was made with the Special Investigations Branch of the Meteorological Office. They supplied details of equivalent tail-wind components from Kinloss to 90° N so that some idea of anticipated fuel figures could be worked out. Also supplied, from a variety of publications, were some basic climatological statistics for the area, e.g. mean cloudiness, probabilities of visibility and wind speed falling within given ranges, and mean temperature figures. Along with this information was a print-out of all surface observations in the North Pole area for the period 16–30 April for both 1986 and 1987, taken from the synoptic data bank, and this contained some useful reports from an ice station which reported regularly in SHIP code.

A couple of articles found in locally held copies of *Weather* and a paper (Meyer 1955) found in a dusty box file (keep something long enough and it will eventually come in useful) gradually built up a picture of what conditions would be like at the time of year in question.

Table I is taken from Koerner's (1970) summary of observations made during the British Trans-Arctic Expedition 1968–69 and shows that the frequency of poor visibility and the incidence of low cloud increased dramatically from April to May.

Conditions at the Pole fall into two quite distinct types with winter characterized by anticyclonic conditions. As temperatures fall in the perpetual night to around −30 to −40 °C, the ice pack freezes over and this effectively leads to a continental-type climate with largely clear skies and good visibilities. In spring (from about May) as the temperature rises, the ice gradually becomes more broken, allowing more and more liquid

Table I. Summary of the April and May observations from the meteorological log of the British Trans-Arctic Expedition, February 1968–June 1969

	Mean temp. (°C)	Visibility (*miles*) < 2½	2½–10	> 10	Cloud Mean total (*oktas*)	Low	Medium	High
		% of total occasions				% of total		
1968								
April	−27	3	6	91	3	14	2	84
May	−10	31	40	29	6	69	9	22
1969								
April	−26	26	6	68	4	56	7	37
May	−09	45	18	37	6	81	7	12

water to evaporate leading to a maritime-style climate in the summer season (August and September) characterized by instances of fogs and low stratus gradually increasing from May until July. This gradually clears in the autumn transition back to the winter conditions.

The trips planned from Kinloss were in late April and early May, so we were now in a position to offer some idea of low-level conditions at the Pole. We were reasonably confident that the April trip would have good conditions but the risk of poor visibility and/or low cloud would obviously be higher on the May trip. I understand that on the basis of the information provided, the May trip was brought forward to as early a date in May as was feasible. It was at this time that I was invited to go on the trips, which covered the route shown in Fig. 1.

Nearer the time of departure, upper-wind charts were ordered from Headquarters Strike Command. These were initially in the form of planning winds which were issued the previous day and based on 1200 GMT data for 36 hours ahead (T+36). The following morning, a further set of upper-wind charts was issued to Kinloss based on 0000 GMT data for T+12, T+18 and T+24 to cover the entire flight. This procedure was repeated for the second flight in early May.

A few weeks prior to the actual flights, it was noticed that another ice station was reporting surface observations from a position very close to the Pole. A regular check was kept on these reports up to the actual flights, and they proved to be most useful when it came to assessing the more detailed low-flying conditions required by the aircrew.

3. The first trip

For the trip in late April there was an anticyclone centred north of Iceland with a ridge extending south-east into the North Sea and a north-westerly airflow from the Pole extending towards northern Scandinavia.

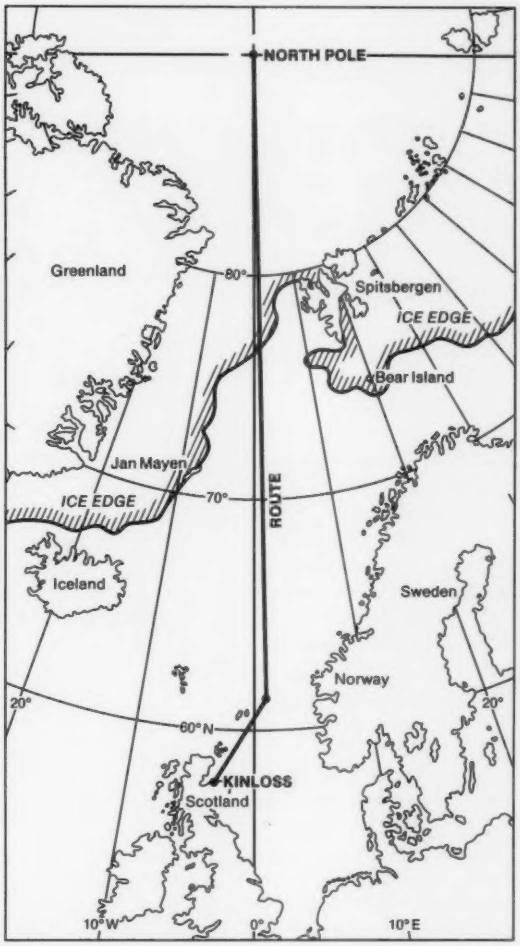

Figure 1. Map showing the route taken on the trips and the position of the ice edge during the period.

This gave an Arctic Maritime air mass over much of the route. Fig. 2 shows the ice edge at 77°N, 01°E from 26 500 feet (FL265) and is a good example of convective cloud streets forming over the open water as the flow moves out from over the ice.

Figure 2. The ice edge with clouds streets forming over the sea.

The latest report from the ice station near the Pole suggested a good deal of altostratus and cirrostratus (Cs) cloud. A good deal of layer cloud was certainly evident as we crossed the ice-cap, but as we approached 90° N I was surprised to find that the ice-cap was visible from our cruising level of FL270. A gradual descent to low level revealed that no cloud actually existed, although a general haze layer extended from around FL230 down to the surface. The airborne visibility slowly improved during the descent until at around FL10 the visibility was estimated at around 30 km in some directions, while in others it was no more than 10–15 km. The visibility did not appear to alter much for the duration of the time we were operating in the region around the Pole.

At low level, the sky did have the appearance, exaggerated by the very low sun, of a layer of Cs but as mentioned earlier no cloud was actually seen. Surface temperatures were reported by the ice station as −17 °C with a surface wind of 15–20 kn giving some low drifting snow. This agreed reasonably well with the values measured from the aircraft at FL10 of −19 °C and a wind of 27 kn.

The ice, as can be seen from Figs 3 and 4, appeared to be very uniform with only a few very narrow cracks which were obviously freezing over rapidly. Many pressure ridges are also in evidence, giving a mosaic pattern as seen from the air. Drifting snow can also be seen in Fig. 4. I was struck by the haziness of the visibility which, as mentioned above, was very variable and quite poor in some directions. However, it did not present too much of a problem for operations at low level. The return trip to Kinloss was largely in darkness and therefore uneventful from my point of view.

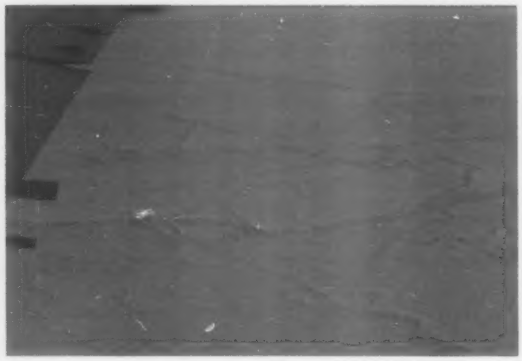

Figure 3. The ice-cap near the Pole.

Figure 4. The ice-cap near the Pole, with crack and refrozen water.

4. The second trip

The second trip in early May was some 10 days after the first. With a depression over northern Scandinavia and its associated occlusion extending south-west across the United Kingdom, an unstable northerly type covered much of the Norwegian Sea as typified by the cumulonimbi in Fig. 5 taken at 69°N, 01°E from FL295.

Figure 5. Cumulonimbi over the Norwegian Sea.

Figure 6. The ice-cap near the Pole, with extensive cracks (compare with Fig. 3).

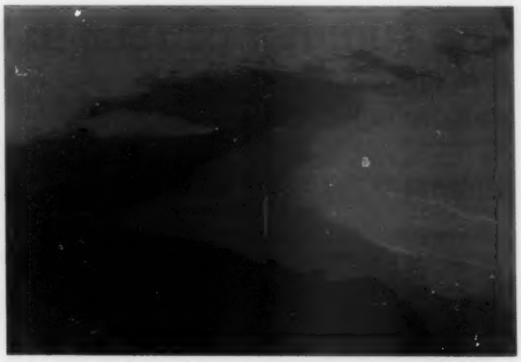

Figure 7. The ice-cap near the Pole, with areas of open water (compare with Fig. 4).

The latest report from the ice station in the region of the Pole showed that the surface temperature had now risen to −10 °C, but apart from this conditions were very similar to those of the previous trip with a reported visibility of 20 km, full cover of upper cloud, and a surface wind of 12 kn. As with the previous trip, although there was a good deal of layer cloud evident as we first crossed the ice-cap, as 90° N was approached, the ice-cap became visible from FL290, and a gradual descent to low level once again revealed no cloud but only a haze layer extending from FL250 down to the surface. The visibility at around FL10 was initially around 20 km but during the time actually spent in the region of the Pole, the visibility became very variable and reductions to around 2000 m were estimated just prior to our departure for home. The poor visibility caused some problems for the aircrew in that all horizontal references became non-existent and the expression 'flying in a goldfish bowl' was used more than once. Once again, the sky had the appearance of a layer of Cs.

The principal difference from the previous trip was the state of the ice-cap, which had now developed many more cracks, some of which were evidently becoming quite wide, with ice only just beginning to form in the open water, see Figs 6 and 7. The trip home was again uneventful, being largely in darkness.

5. Comments

It is now clear that the transition from winter to summer had already begun at the edges of the ice-cap with the ice becoming more broken allowing liquid water to be evaporated into the atmosphere, which then quickly cools by advection over the still-cold ice to form the fogs and low stratus typical of the Arctic summer. The gap in the cloud cover at the Pole itself indicates that the transition had not quite reached 90° N and suggests that the data supplied to the Royal Air Force were both accurate and useful.

Acknowledgements

I am indebted to K. Grant in the Special Investigations Branch and S. Wattam at Headquarters Strike Command for all their patient support during the preparation for these trips. I am also indebted to Squadron Leader Heppenstall, 206 Squadron, Royal Air Force Kinloss for allowing me to go on journeys not likely to be repeated for quite some time.

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The summer of 1988 in the United Kingdom

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Summary

Most parts of the United Kingdom had a somewhat average summer, although the seasonal rainfall values tend to conceal a very wet July which compensated for a dry June.

1. The summer as a whole

Mean temperatures during the summer were generally near normal. Most parts of Scotland, the Isle of Man and parts of North Wales were a little above normal, reaching 0.6 °C above normal in central Scotland, whereas in most other areas temperatures were slightly below normal, and in some parts of southern England nearly 1 °C below normal. A dry June followed by a very wet July and a wet August gave rainfall amounts close to average in the east but above average in western areas, reaching nearly twice the normal in parts of Cumbria. Eastern Kent, however, had less than half the normal. Sunshine amounts were near or below average generally; the brightest conditions were in eastern Scotland and north-east England, but it was dull elsewhere, especially in western areas.

Information about the temperature, rainfall and sunshine during the period from June to August 1988 is given in Fig. 1 and Table I.

2. The individual months

June. Mean monthly temperatures were slightly above normal in most areas, but below normal in parts of the east Midlands, East Anglia and south-east England, ranging from nearly 2 °C above normal at Ronaldsway, Isle of Man to more than 0.5 °C below normal in East Anglia and eastern Kent. Monthly rainfall amounts were generally below normal and at Glasgow Airport only 17% of the average fell. However, over parts of South Wales, the Midlands and East Anglia, amounts were locally above normal, reaching 143% at Aberporth, Dyfed. England and Wales as a whole had the driest June since 1976, and Scotland the driest this century. Many places had record low rainfalls; Glasgow Airport had only 10 mm, equalling the amounts recorded in 1921 and 1925 for the driest Junes in a record which, at various sites around Glasgow, goes back to 1868; Worthing, West Sussex had as little as 9 mm of rain during the whole month. Monthly sunshine amounts were generally above normal in Northern Ireland, North Wales, northern England and most of Scotland, reaching 123% of normal at Eskdalemuir, Dumfries and Galloway, but below normal in northern Scotland, South Wales and the remaining parts of England, and as low as 59% of normal at Cromer, Norfolk.

Many areas had some rain during the first few days of the month, with heavy falls and thunderstorms locally. Further rain affected western areas on the 6th, and an area of quite heavy rain moved south-westwards over England and Wales on the 8th and 9th. Dry weather

Table I. District values for the period June–August 1988, relative to 1951–80 averages

District	Mean temperature (°C)	Rain-days	Rainfall	Sunshine
	Difference from average		Percentage of average	
Northern Scotland	+0.3	+1	113	85
Eastern Scotland	+0.3	+2	109	98
Eastern and north-east England	0.0	+2	121	69
East Anglia	−0.3	+3	106	90
Midland counties	−0.1	+3	118	91
South-east and central southern England	−0.5	+2	94	90
Western Scotland	0.0	+3	133	97
North-west England and North Wales	−0.2	+2	113	94
South-west England and South Wales	−0.4	+4	133	85
Northern Ireland	+0.1	+2	116	93
Scotland	+0.2	+2	120	93
England and Wales	+0.3	+3	115	92

Highest maximum: 30.2 °C in the Midlands in August.
Lowest minimum: 0.6 °C in western Scotland in June.

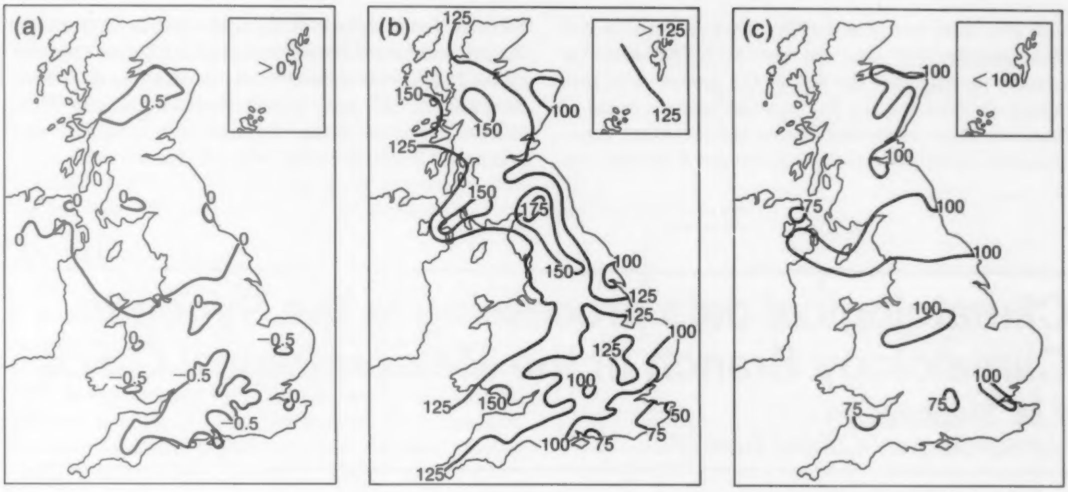

Figure 1. Values of (a) mean temperature difference (°C), (b) rainfall percentage and (c) sunshine percentage for summer, 1988 (June–August) relative to 1951–80 averages.

then prevailed until the last week of the month, apart from some heavy thunderstorms in the south-east on the 20th. Scotland had a very pleasant summer month, the best since the fine summer of 1984, although low cloud and fog affected coastal areas from time to time, keeping temperature and sunshine near normal in some places. For the closing days of the month the weather turned showery with thunder in places although there was still some dry, sunny weather, especially in Scotland.

July. Mean monthly temperatures were below normal everywhere except northern and eastern Scotland and ranged from 1.0 °C above normal at Lerwick, Shetland to 1.9 °C below normal at Lyneham, Wiltshire. Rainfall amounts were well above average in most places, although in the extreme south-east of England amounts were near or below normal in some places, ranging from more than three times the normal at Carlisle, Cumbria to 83% of normal at Manston, Kent. Some long-standing records were broken: it was the wettest July over England since 1936 and Wales since 1939, and the wettest July in Scotland since records began there in 1869. Sunshine totals were below the average nearly everywhere, although some places in eastern Scotland and in the Western Isles had near or just above average totals, ranging from 115% of average at Tiree, Strathclyde Region to 64% at Exeter, Devon.

Rain or showers, the rain heavy at times and sometimes accompanied by thunderstorms, occurred over some parts of Great Britain on nearly every day. Between the 18th and 20th it was generally dry, but with some rain in western parts of Wales. Many of the month's major events were disrupted in some measure: the Royal Agricultural Show ground at Stoneleigh, Warwickshire became waterlogged after heavy rain on the 4th and among sporting fixtures disrupted were the Tennis Championships at Wimbledon, which were virtually washed out on the 3rd, and the Open Golf Championship at Lytham St Anne's. Both these championships had to be extended by a day to allow the competitions to be completed, and the British motor racing Grand Prix at Silverstone, Northamptonshire was run in very wet conditions. Thunderstorms occurred widely between the 1st and 8th, mainly over England. There were further thundery outbreaks from time to time, widespread over southern England on the 26th.

August. Mean monthly temperatures were near or below normal nearly everywhere in the United Kingdom, ranging from above normal in some eastern parts to more than 1 °C below normal in parts of north Devon. Monthly rainfall totals were above normal in most of Scotland, Wales, Northern Ireland and parts of north-west and south-west England and below normal elsewhere, ranging from half the normal in the coastal areas of East Anglia and Kent to more than twice the normal at Tiree, Strathclyde Region. Sunshine amounts were generally above normal in England and Wales north-east of a line from about Rhyl on the coast of North Wales to Southampton on the south coast, but below normal elsewhere, ranging from more than 120% in places in north-east England and on the Suffolk coast to less than 60% in western Scotland.

The month began rather unsettled with occasional rain chiefly in northern areas. However, it was dry nearly everywhere from the 5th to 8th, and at Anvil Green, Kent it was dry for the first 17 days. It was very wet on the 12th in parts of northern England and in central and northern Scotland, particularly around Glenmore and the Moray Firth. Most places in northern and western areas of Great Britain had a wet day on the

14th and, after two generally dry days on the 15th and 16th, another wet day on the 18th. The unsettled weather persisted for the rest of the month, with rain falling on almost every day in some western areas of England, more especially during the last three days. Thunder, sometimes with hail, occurred around the Firth of Forth and the coast of north-east England on the 1st, and across central and eastern parts of England on the 2nd; scattered thunderstorms occurred in western Scotland on the 14th, central Scotland on the 18th, eastern England on the 19th and 20th, and east and south-east England on the 28th and 31st.

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Climatological data processing in the Synoptic Climatology Branch of the Meteorological Office

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Summary

A description is given of the collection, quality control and archiving of world-wide climatological data carried out by the Synoptic Climatology Branch of the Meteorological Office.

1. Introduction

The availability of climatological data on a global basis is becoming increasingly vital to many users both inside and outside the Meteorological Office. The data are requested by a wide variety of commercial and industrial bodies, for instance, who may need it for applications such as agriculture, civil engineering or aviation. They are needed for research, such as that carried out in the Synoptic Climatology Branch into atmospheric variability on time-scales from 10 days (which benefits long-range forecasting) to a season (used as the basis of the successful seasonal tropical rainfall forecasts). Also, the increasing concern that man may be changing the climate of the earth through emissions of greenhouse gases has lent an urgency to the monitoring of global climate change.

To fulfil such needs it is essential to maintain a comprehensive, accurate and up-to-date bank of climatological data on a world-wide scale extending back over a large number of years. This has been the responsibility of the CLIMAT section of the Branch for many years, with an increasing emphasis recently on the use of computers for both storing and retrieving the data.

2. The CLIMAT system

A selection of meteorological observing stations throughout the world are designated as CLIMAT stations by the parent country, at the request of the World Meteorological Organization (WMO). At the end of each month these stations are required to transmit their climatological data for the month using the CLIMAT (surface) and CLIMAT TEMP (upper-air) codes. At present (1988) there are over 2000 CLIMAT stations and about 450 CLIMAT TEMP stations.

The CLIMAT code is used to report monthly mean and total values of surface data and the CLIMAT TEMP code reports monthly mean values of upper-air data, together with the number of days of data used to compute the monthly mean. Ocean Weather Ships report similar data using the CLIMAT SHIP and CLIMAT TEMP SHIP codes.

This article is concerned primarily with the CLIMAT (surface) data processing system used by the Synoptic Climatology Branch of the Meteorological Office. An outline flow chart of the processing is shown in Fig. 1. A similar system for handling CLIMAT TEMP (upper-air) data is in an advanced stage of development.

3. Sources of data

3.1 Recent data

The primary means of data reception since 1980 has been the Global Telecommunication System (GTS). Data are received via the GTS at the Meteorological Office telecommunication centre and are fed automatically into the Synoptic Data Bank (SDB) where the CLIMAT messages are separated from the synoptic messages, ready for processing by the Synoptic Climatology Branch.

Unfortunately not every country's data survive the passage through the GTS, either through faulty transmission in the country of origin, or perhaps through loss at a collecting centre *en route*. It is usually possible to fill in most of the gaps by means of confirmatory teleprinter messages or, somewhat in

arrears, by data sent through the mail or (even more in arrears) from the publication *Monthly climatic data of the world*, issued by the National Climatic Data Center (NCDC) at Asheville, North Carolina. This publication makes use of data received on forms as well as via the GTS. It is the ambition of the WMO to make the dissemination of CLIMAT data fully automatic, but this is a long way from being realized at present.

3.2 Historical data

Data for the period from 1738 to 1980 are derived primarily from a magnetic tape supplied by the NCDC, supplemented by unpublished manuscript data collected by the Meteorological Office, dating back to about 1937. Data published by other National Meteorological Services and the NCDC publication *World weather records*, issued at 10-year intervals, are also proving useful sources of historic data.

4. Content of the data

At the present time, CLIMAT stations are required by the WMO to report monthly means or totals of the following elements:

station-level pressure,
mean-sea-level (MSL) pressure,
air temperature,
vapour pressure,
number of days with rainfall equal to or exceeding 1.0 mm,
rainfall, and the quintile into which it falls,
hours of sunshine, also expressed as a percentage of the monthly normal, and
sea temperature (Ocean Weather Ships only).

Data collected prior to the 1960s normally consist only of pressure, air temperature and rainfall.

5. Quality of the data

Since the automation of the Meteorological Office CLIMAT system in 1986, comprehensive automatic quality control has been carried out, supplemented by visual inspection of data on screens, print-outs and plotted charts. See section 8 for a description of the automatic quality-control procedures.

Some of the earlier manuscript data were subjected to visual scrutiny for gross errors. They were then plotted on charts and their deviations from climatological means were compared with values for the same month at neighbouring stations, as well as with other months and years at the same station. Values judged subjectively to be unacceptable were deleted, unless a corrected value was found later in the relevant issue of *Monthly climatic data of the world.*

No systematic quality control of data on the NCDC magnetic tape has been carried out, but some discrepancies have been detected and corrected, where possible, in the course of using the data. Typical errors found have been incorrect temperatures, apparently due to double conversion from degrees Fahrenheit to degrees Celsius;

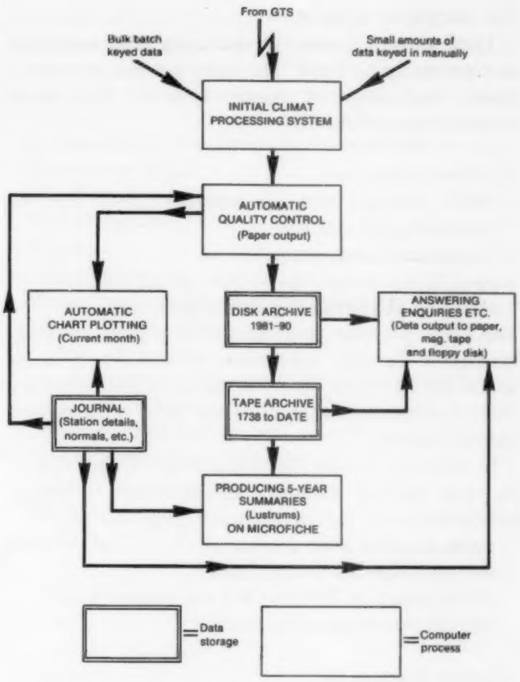


Figure 1. The logical flow of data through the CLIMAT system.

WMO procedures for reporting or correcting to MSL pressure at very high-level stations not being followed; and discontinuities resulting from stations changing site while retaining the same WMO station number. There are also significant gaps in the records for some stations. These are being filled in, if the data are available from our manuscript records or from *World weather records*, as resources permit.

6. Storage of the data

Data for the current decade are stored on disk and updated every month, one month in arrears. At the end of each month the tape of NCDC-derived data is also updated using the disk data, thus producing a comprehensive magnetic tape archive covering the period from 1738 to date. The data are stored using a software system developed by the Meteorological Office, known as GPACCESS. This makes storage and retrieval as efficient as is possible with magnetic tape.

7. Presentation and accessibility of the data

7.1 Lustrum books

Five-year summaries of the data, on a station-by-station basis, are produced on microfiche at regular intervals. This is a continuation of the long-established practice of entering CLIMAT data manually in 'lustrum books'. The 'old' lustrum books are still available in the Synoptic Climatology Branch.

7.2 Monthly charts

These are now plotted automatically by the computer and drawn up by hand. The latter process provides a useful final stage of quality control. The charts produced are as follows:

Northern hemisphere

MSL pressure and its anomaly from 1951–80 climatological means,
temperature and anomaly,
rainfall and percentage of 1951–80 normals, and
sunshine and percentage of normals.

The MSL pressure analysis uses a gridded monthly average of the daily operational 00 GMT analyses as well as the CLIMAT data. The MSL pressure anomaly chart is produced by gridding the MSL pressure and normals charts.

In order to examine the relationship between upper-air and surface features, an additional northern hemisphere chart is formed from a composite of:

mean monthly MSL pressure,
500 mb ridge and trough lines,
50 kn isotach at 300 mb (40 kn in summer), and
rainfall percentage of normals.

Southern hemisphere

MSL pressure and anomaly, and
temperature and anomaly.

Some southern hemisphere charts are received from the Australian Bureau of Meteorology in Melbourne.

A selection of northern hemisphere charts for the most recent 3 months is displayed, for ready appraisal, on the wall of the CLIMAT Laboratory in the Synoptic Climatology Branch. These are frequently used in providing background information to global weather events, such as the Bangladesh floods in 1988.

7.3 Retrieval of data

A standard retrieval program is available which will extract data in chronological order for any given station. An alternative program will print out all the data for all stations for any given month. If required, the data can also be copied to magnetic tape or floppy disk.

7.4 The Journal

Details of all the stations for which data are collected are stored on a disk data set, commonly referred to as the 'Journal'. These details include the station name, its latitude, longitude and height together with 1951–80 normals for each of the elements (temperature, pressure, etc.) if these are available. This information is required by the computer programs which plot, quality control and retrieve the data (see Fig. 1).

8. Automatic quality control

The main part of the quality control is performed in three stages for each element for each station.

(a) Each value is checked to see whether it lies outside previous extreme limits.

(b) Each value is checked against upper and lower confidence limits which are (apart from rainfall) three times the standard deviation above and below the normal. In the case of rainfall an empirically defined upper limit is used, derived by adding to the average 1.5 times the second highest monthly anomaly recorded for the station. The lower limit is derived similarly but, if negative, is set to zero.

(c) The normalized anomaly (i.e. anomaly divided by standard deviation) for each value is compared with the normalized anomalies at six neighbouring stations and is queried if, for most elements, it differs by more than 0.7 from the mean of them and by more than 3.0 times their standard deviation. For vapour pressure and all three rain indices (rain-days, rainfall and quintiles) these limiting criteria become 1.5 and 4.0 respectively.

In addition:

(d) A check is made of the relation between MSL pressure and station-level pressure and, if possible, surface temperature and station height.

(e) Rain-days and rainfall are compared — a day with 1.0 mm of rain or more must be classed as a rain-day. Also, if the rainfall is zero, the number of rain-days must also be zero.

(f) Vapour pressure is checked to ascertain that it is not greater than saturation vapour pressure.

(g) Sunshine and its percentage of normal are used to check that 100% of the implied normal sunshine does not exceed total daylight.

(h) A check is made for lack of negative correlation between MSL pressure and rainfall.

Except in the case of (a) suspect values are not rejected outright, but are examined on plotted charts and if they look inconsistent with surrounding stations are compared with the mean of daily values from the SDB and replaced if possible. It is sometimes also possible to replace a suspect value at a later date with one from *Monthly climatic data of the world*. Changes are made to the data via a computer terminal.

Acknowledgements

Much of the initial design work and computer programming for this system was carried out by M. Jackson and J.R. Lavery, while the procedures for computing the 1951–80 normals and for quality controlling the data were developed by B. Collison. Subsequent implementation and further development have been in the hands of the author, assisted by J. McCoy who, together with B. Harlock, also looks after the day-to-day running of the system.

Notes and news

Joint Opportunities for Unconventional or Long-term Energy supply (JOULE)

The European Economic Community funds a programme of Research and Technological Development in the area of non-nuclear energy and the next phase of the programme covers the period 1989–92. JOULE is a 3¼-year programme which was scheduled to start on 1 January 1989 but which now comes into force in spring 1989, when it is due to be ratified by the Community Council.

The objectives of JOULE are:

(a) Increasing long-term security of energy supply and reducing energy import by Community countries.

(b) Alleviating environmental problems related to energy use.

(c) Improving the Community competitiveness through reduced energy costs.

(d) Establishing standards for energy production assessment.

(e) Solving technical problems in energy production.

The Commission of the European Communities has recently issued the invitation to research organizations in the Community countries to apply for funding. Two areas of research and development under the general title of 'Solar-derived renewable energy sources' may be of interest as having meteorological associations. These are:

(a) Wind energy — The principal objective of this programme is to decrease the cost of wind-derived electricity through improvements to cost, performance and lifetime of wind turbines. Part of the programme is devoted to the study of the types of site to be favoured for turbines, such as those with complex topography which concentrate the wind naturally; this could involve modelling and measurement of turbulent winds in mountainous terrains.

(b) Biomass — In this area, the main objective is the development of techniques for the production, conversion and use of fuel from plants with the ultimate aim of providing 10% of Community energy requirements. Research is being promoted on specific promising 'energy crops' and their preferred areas of growth, and also their harvesting, transport and storage.

The Meteorological Office has climatological data available to support these programmes of research, particularly measurements of wind, temperature and rainfall, and derived quantities such as soil moisture deficit. Recently, *Climatological data for Agricultural Land Classification* for England and Wales have been compiled and published by the Meteorological Office.

Further details about JOULE are given in an information package obtainable from:

Commission of the European Communities
Directorate XII/E
200, Rue de la Loi
B-1049 Brussels
Belgium

for the attention of:
Mr G. Caratti di Lanzacco (Wind energy)
or Mr D. Pirrwitz (Biomass).

Alternatively further information can be obtained from:
Dr S.E.R. Hiscocks
Department of Energy
Energy Technology Division
Thames House South
Millbank
London SW1P 4QJ.

Reviews

An introduction to boundary layer meteorology, by R.B. Stull. 165 mm × 246 mm, pp. xii+666, *illus.* Dordrecht, Boston, London, D. Reidel Publishing Company, 1988. Price Dfl.220.00, US $99.00, £64.00.

In preparing this book, the author set himself some daunting goals — to combine in a single volume, a wide-ranging textbook for students, a reference work for researchers as well as a literature review of current ideas and methods. Professor Stull is an established researcher in the field of boundary layer meteorology although inevitably, as he himself admits, not an expert in all the areas covered. Perhaps equally inevitably, the book is not a complete success but nevertheless represents a brave attempt to reach an ambitious goal. Although there are already a number of fine textbooks concentrating on various aspects of the subject, there is nothing else which provides as broad a coverage as this volume.

The book starts with a general description of the physical characteristics of the boundary layer, after which the basic statistical tools (means and first-order correlations) used to describe turbulence are introduced. These tools are then employed to derive the Reynolds-averaged equations for means, variances and turbulent fluxes. The physical processes that generate turbulence and their relative importance are analysed with reference to the turbulent kinetic energy budget, leading on to a discussion of stability and scaling. A chapter is

then devoted to turbulence closure techniques and another to boundary conditions and external forcings. There is a useful, basic introduction to time-series and the methods used to analyse them, followed by a chapter which calls on some of this material to discuss spectral similarity, after first considering mean-flow similarity. The final five chapters are more in the form of a literature review covering measurement and simulation techniques, convective and stable boundary layers, boundary layer clouds and geographic effects. Throughout the book, copious use is made of data from observations and simulations to illustrate the phenomena discussed and the range of values of parameters which might be encountered. Within the text there are numerous worked examples, while a large number of exercises (without answers) are provided at the end of each chapter. A list of general references, mainly other text books, is given in chapter 1, while each of the other chapters contains numerous references to research papers, many of them very modern. A useful list of field experiments is included, as are tables of scaling variables and similarity relationships which have been used in the literature.

In order to obtain the desired, wide-ranging coverage, the author has clearly been obliged to restrict the detail in which each particular topic is covered. I do not feel, however, that he has achieved the optimum balance. Given that the major audience is intended to be students with an undergraduate background in meteorology, it seems inconsistent to assume that their mathematical knowledge is so low as to warrant the detail in which simple algebraic manipulations are given in chapters 2–4. The space devoted to this could have been better used in providing further detail where the analysis is less straightforward. Students would also have been better served if specific references to other textbooks, rather than research papers had been given, where appropriate. One might also question the wisdom of devoting whole pages to sequences of diagrams which merit only one or two sentences of comment in the text. The coverage of slightly less material in slightly more detail would have been more satisfactory.

There is a tendency throughout the book not to discriminate clearly enough between actual observations and model simulations of data. The author's style is, on the whole, descriptive rather than critical, which is unfortunate in a subject where so much uncertainty exists and, in particular, leads to an over-optimistic impression of the capabilities of models. It also means that it is often unclear whether or not a particular assertion is generally accepted. There are certainly numerous statements with which some other workers would take issue and at least one to which everyone should take exception: the aerodynamic roughness length is *not* 'the height where the wind speed becomes zero', as claimed on page 378. Any student who accepts this statement at face value will indeed have been done a significant disservice.

Turning finally to editorial matters, the text appears to have been produced directly using a fairly unsophisticated desk-top publishing system. This has generated an aesthetically unpleasing change of line spacing where superscripts or subscripts appear in the text and a crude representation of broken lines in the diagrams. There are also a significant number of typographical errors, the most annoying of which are references to equations which don't exist!

In spite of its shortcomings, the book does provide a useful, broad introduction, both for students and researchers new to the field. It could provide a useful basis for courses in which a limited amount of the material was treated in more detail. It is a good source of references for the more experienced researcher, although inevitably, those substantial sections which are in the form of a literature review will rapidly become outdated. I suspect that few individuals will be prepared to pay £64 for the hardback edition, although the paperback should be more attractive.

M.K. MacVean

Applications of remote sensing to agrometeorology, edited by F. Toselli. 164 mm × 236 mm, pp. viii+326, *illus*. Dordrecht, Boston, London, Kluwer Academic Publishers, 1988. Price Dfl.200.00, US $99.00, £64.00.

This book is one of a series on remote sensing, based on courses held within the framework of 'the ISPRA-courses'. It is aimed at scientists active in agrometeorology and related fields; the course objective was to provide information on the state of the art and on prospective developments in this field.

My interest in this book was caught by the word 'Applications'. When I last looked, remote-sensing techniques were yet to have such impact in the day-to-day management of agriculture. They remained a solution in search of a problem, with an application limited to the wide open spaces, flat terrain and cloud-free skies of Africa, USSR or North America, not to the cloud-covered agriculture of north-west Europe. Had things changed?

To say 'Not much' would be unfair. If you are looking for a list of novel, off-the-shelf, remotely sensed products ready to supplement or replace existing, surface-based instrumentation, then it is true that you will be disappointed. But that would be asking too much of the technology in its present state of development. The message implicit in this book is: that to use those products that do exist, and certainly to develop new ones, it is still necessary to have a considerable understanding of the mechanics of remote observation.

Over two-thirds of the book is devoted to the science of remote sensing, with only passing or token reference to plants or agriculture. The subject matter is treated in satisfactory depth, progressing from 'fundamentals'

through 'sensors' and 'platforms', before devoting a large number of pages to 'data' and 'image processing'. It goes sufficiently beyond the principles, that it is possible to find, for example, the orbital characteristics of various operational satellites. A particularly pleasing aspect of the book is the wealth of tables, and quantitative and well produced diagrams.

The reader interested in the practical use of tele-detection will with relief reach the last five chapters which deal with applications: 'surface temperature', 'surface radiation budget', 'soil moisture', 'rainfall', and the derivation and interpretation of a 'vegetation index'. For the first time we are able to leave behind the technology, and begin to be persuaded that, in spite of the difficulties, much can be inferred about the growth, moisture, status and even the yield of a crop. I was glad to learn, for example, that microwave techniques now offer an operational method of routine soil moisture estimation. In the USSR, radiometer data from aircraft contribute soil-moisture information for the management of a land area of 150 000 km^2, with substantial cost savings over conventional techniques.

Overall the book delivers what it promises. The scientist already experienced in remote-sensing technology, but not in its practical use, will find the 'applications' chapters very useful, particularly those on 'vegetation index', and 'soil moisture' and 'evaporation', and will discover principles that govern a whole philosophy of applications: for example, 'Radiance properties of vegetation provide more information about the processes than about the state of crops'. Thus it is easier to estimate growth stage, say, than biomass or leaf area. The scientist who is about to get seriously involved in using or developing remotely sensed products in a soil-related discipline will find this an excellent primer. No doubt the subjects of 'sensors', 'platforms' and 'data processing' separately fill many textbooks, but this book gathers them under one cover in sufficient detail to equip the reader to venture, where necessary, into more advanced volumes.

B.A. Callander

Ice shelves of Antarctica, by N.I. Barkov, translated from the Russian by Lt Comdr P. Datta, 160 mm × 245 mm, pp. viii+262, *illus.* Rotterdam, A.A. Balkema, 1985. Price Hfl. 85.00, £20.75.

This book was first published in Russian in 1971. At that time it represented a valuable compilation of material related to the study of ice shelves — an almost exclusively Antarctic phenomenon. These large floating plates of ice, fed by the outward flow of grounded inland ice and by surface snow accumulation, are important and sensitive indications of the general health of the Antarctic Ice Sheet, and hence of climatic influences. In their own way they provide a restraining force on potentially unstable areas of ice such as that grounded below sea level in West Antarctica. Ice loss by bottom melting yields cold, high density water, important oceanographically in the production of Antarctic bottom water. The calving of large tabular icebergs is both spectacular and hazardous, providing the greatest single component of ice-sheet ablation.

At the end of the 1960s, when this book was written, only very preliminary reconnaissance information was available on ice shelves. Some had been studied during the IGY and a primitive understanding had emerged of their dynamics, thermodynamics, mass balance and role in climate-related processes. This book should therefore be reviewed as an historical summary of information and ideas available up to the 1970s. It is not a state-of-the-art summary.

Chapter 1 provides a brief historical review of the exploration of ice shelves. Chapter 2 examines factors relevant to the formation and continued existence of ice shelves (topographic, oceanographic, climatic). Chapter 3 describes morphologic features of ice shelves and chapter 4 the mass balance of ice and snow to ice shelves. Chapter 5 is concerned with snow and ice structure, principally from bore-hole studies, and chapters 6 and 7 with the thermal regime and motion of ice shelves, with theoretical treatments. Chapter 8 deals with the present state of ice shelves, their response to climate and past fluctuations, and the final chapter considers this classification.

The overriding weakness of this book is its age. The bulk of the references centre around 1961–66. No account is taken of the enormous advances to ice-shelf studies during the last 15 or more years, particularly the results of the Ross Ice Shelf Project (surface glaciology, core drilling, observations beneath the ice shelf, associated oceanography, ice thickness and other geophysical measurements) and the substantial contribution from studies of the Amery Ice Shelf and the on-going Filchner-Ronne Ice Shelf Project. Concepts developed during the last decade of the role of ice shelves in the stability of the West Antarctic Ice Sheet, and the former extent of these ice masses, do not figure.

The illustrations, mainly reproduced from the Russian edition, vary in quality — the black and white photographs are totally unacceptable. There is no index, and the translation into English leaves much to be desired. Typographical errors abound and many place names or scientific terms have curious and inconsistent forms. In summary, it is good to have Barkov's book in English translation, but it is just years too late!

D.J. Drewry

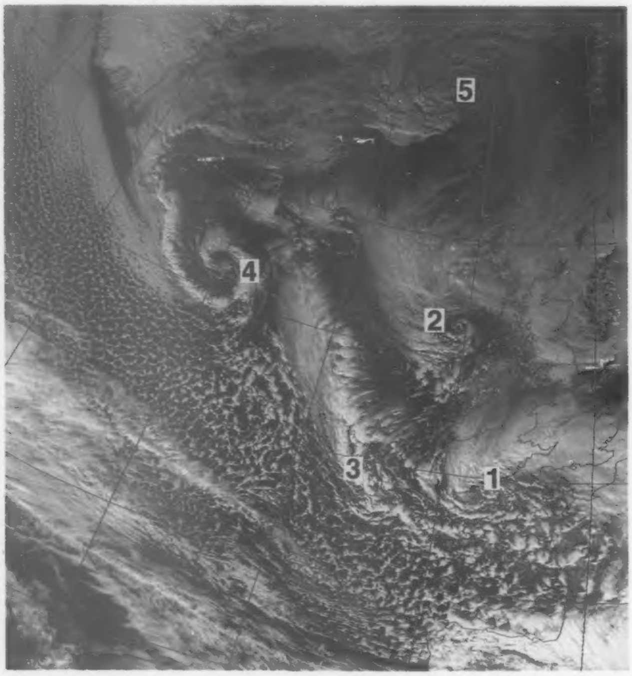
Correction

Meteorological Magazine, March 1989, p. 60, ll. 8–11. The sentence 'In flight, . . . below −76°C.' should have read: 'For these flights, forecasts were required for the diversion airfield of Rio Gallegos in southern Argentina as well as forecasts of areas of CAT and regions of ambient temperatures below −76 °C.'

Satellite photograph — 25 February 1989 at 1418 GMT

This visible image illustrates an excellent example of convection over the Atlantic Ocean during a cold north-westerly airstream. Open cellular convection is seen within a broad zone from the Davis Strait to France and Iberia. This convective regime is bounded in the south by a weak but distinct surface front lying west to east (note the rope cloud near the southern edge of the picture) and to the north-east by several polar lows (labelled 1–4), themselves containing convective cloud, but mostly surrounded by regions where considerable suppression of convection is apparent. The circulation labelled '5' was the filling remains of the frontal depression behind which the cold air outbreak was initiated.

Small-scale troughs or convergence zones where surface pressure gradients change markedly (Fig. 1) are associated with polar lows 3 and 4. The life histories of the vortices 1 to 5 derived from NOAA-10 and -11 images are shown in Fig. 2. Most persisted for several days, and circulated cyclonically near the periphery of a deep upper-tropospheric vortex centred over northern Britain. The apparently innocuous vortex labelled 1, had a central pressure of 950 mb, a value which it retained as it moved eastwards across southern England. Exceptionally strong winds occurred on its southern flank, leading to the sinking of at least one ship, considerable other damage and related loss of life over southern France and Iberia.



Photograph by courtesy of University of Dundee

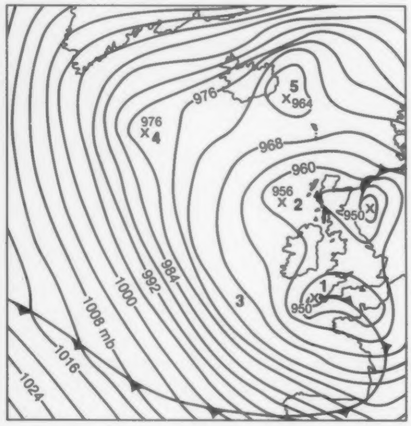


Figure 1. Surface analysis at 1200 GMT 25 February 1989.

Key

D = First or last observation of vortex
Adjacent figures give dates
○ NOAA-11 0220–0450 GMT
+ NOAA-10 0825–0940 GMT
□ NOAA-11 1225–1435 GMT
△ NOAA-10 1845–2035 GMT
■ NOAA-11 1415 GMT 25 Feb.
Adjacent figures refer to vortex number

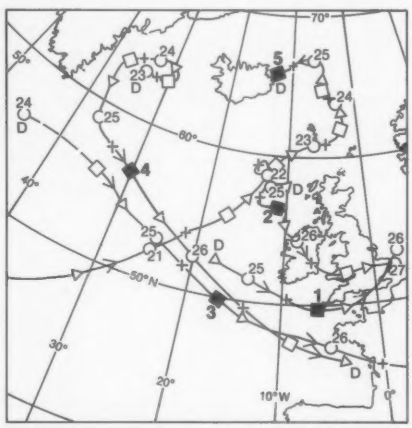


Figure 2. Life cycle of vortices 1 to 5 (indicated on the satellite image) during the period 21–27 February 1989.

Meteorological Magazine

GUIDE TO AUTHORS

Content

Articles on all aspects of meteorology are welcomed, particularly those which describe the results of research in applied meteorology or the development of practical forecasting techniques.

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Articles, which must be in English, should be typed, double-spaced with wide margins, on one side only of A4-size paper. Tables, references and figure captions should be typed separately.

Spelling should conform to the preferred spelling in the *Concise Oxford Dictionary*.

References should be made using the Harvard system (author, date) and full details should be given at the end of the text. If a document referred to is unpublished, details must be given of the library where it may be seen. Documents which are not available to enquirers must not be referred to.

Tables should be numbered using roman numerals and provided with headings. We consider vertical and horizontal rules to be unnecessary in a well-designed table; spaces should be used instead.

Mathematical notation should be written with extreme care. Particular care should be taken to differentiate between Greek letters and Roman letters for which they could be mistaken. Double subscripts and superscripts should be avoided, as they are difficult to typeset and difficult to read. Keep notation as simple as possible; this makes typesetting quicker and therefore cheaper, and reduces the possibility of error. Further guidance is given in BS1991: Part 1: 1976 and *Quantities, Units and Symbols* published by the Royal Society.

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